

D5.2

List of best available BbS and technologies and inventories of existing technologies

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LIST OF ACRONYMS

ATEX: ATmosphere Explosible
BbS: Bio-based Systems
CNSL: Cashew nutshell liquid
G2PG: Glycerin to Propylene Glycol
HMF: Hydroxymethylfurfural
LCA: life Cycle Assessment
PG: Propylene Glycol
TRL: Technology Readiness Level

PROJECT INFORMATION

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List of participants:

PARTNER N°	PARTICIPANT ORGANIZATION	ACRONYM
1 (Coord.)	CONTACTICA SL	CTA
2	AALBORG UNIVERSITET	AAU
3	LUXEMBOURG INSTITUTE OF SCIENCE AND TECHNOLOGY	LIST
4	INSTITUT NATIONAL DES SCIENCES APPLIQUEES DE TOULOUSE	INSA
5	NORGES TEKNISK-NATURVITENSKAPELIGE UNIVERSITET	NTNU
6	BIOECONOMY FOR CHANGE	B4C
7	BUSINESS E-INCUBATOR GO-UP	GOUP
8	FUNDACION CENTRO DE SERVICIOS Y PROMOCION FORESTAL Y DE SU INDUSTRIA DE CASTILLA Y LEON	CESEFOR
9	SONAE ARAUCO PORTUGAL SA	SONAE
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DELIVERABLE DETAILS

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Authors:	Audrey Magnin (B4C) Régis ESSIS (B4C) Omar Bayomie (INSA) Carlos Robles Rodriguez (INSA) Aras Ahmadi (INSA) Ligia Barna (INSA) Tamara Coello (CESEFOR) Paolo Jorge Magalhaes (SONAE)
Reviewers:	Lucia Garcia (CTA)
Abstract:	This Deliverable (D5.2) of the LCA4BIO project, titled "List of best available BbS and technologies and inventories of existing technologies," focuses on the identification and selection of the best available BbS and technologies at industrial scale in the relevant sectors. The methodology combines a literature review with expert interviews, applying selection criteria based on data availability, process maturity, and sectoral representativeness.

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v1.0	04.06.2025	First draft for review
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v3.0	07.07.2025	Final version for submission
v4.0	27.10.2025	Revised version for submission

1 INTRODUCTION

Based on the stakeholders' analyses performed in task 7.3 (stakeholder engagement), the aim of this report is to identify the best available Bio-based Systems (BbS) and technologies at industrial scale regarding environmental and circularity performance in relevant sectors, including at least woodworking and bio-chemicals.

B4C, INSA, SONAE and CESEFOR ensured the collection of information and limited confidentiality issues. D5.2 presents the work performed on this subject and deals with the selected systems and technologies, as well as the quantified values to benchmark.

2 METHODOLOGY

Two major actions were undertaken to select the most interesting BbS to test the different methodologies developed in the LCA4BIO project, which will be reported in D5.1.

1. **Identification of Best Available BbS and Technologies.** Building upon the stakeholder analyses performed in Task 7.3, the initial phase focuses on identifying BbS and technologies that show strong environmental and circularity performance within relevant sectors, with a particular emphasis on woodworking and bio-chemicals. A selection was made on the table 3 of the deliverable 7.7, focusing on stakeholders that produces or aims at producing biomolecules (ADM, BASF, Michelin, Naturamole etc.). However, to be sure to have a sufficiently large list, it was extended with other resources: IAE Bioenergy, Bio-Based Chemicals 2020 Update (Ed de Jong et al., 2020) and the member list of the cluster Bioeconomy for change (Bioeconomy for Change, 2025). Information for each molecule was collected on public resources, mainly website of the companies and publications from research laboratories. This resulted in the list of molecules described in Section 3.
2. **Selection of case studies.** A comprehensive literature review was conducted to characterize each molecule and gather information about each BbS (Section 4). This information was used to identify case studies, which are based on data availability (preference were given to processes for which data were already accessible in established Life Cycle Assessment (LCA) databases, e.g., Ecoinvent, and existing LCA studies); the maturity as new processes may be subject to higher confidentiality, whereas mature processes shared by competitors in the sector may offer more accessible data and representativeness to ensure that the findings are broadly applicable. The complete criteria to define the case studies are shown in Section 5.

3 LIST OF MOLECULES AND ASSOCIATED COMPANIES, PROCESS AND TRL

Based on the methodology presented above, the following list of molecules along with their associated companies, process and Technology Readiness Level (TRL) was elaborated.

To make the list as consistent as possible, specific attention was given to the representativity of the chemical class of molecules (esters, aromatics, alcohol, acids, lipids) with various TRL and applications. Producers considered are mainly French and members of B4C to maximize the proximity and the possibility to interact in case of selection as a case study and being able to provide data when possible.

The type of production, application and whether or no these processes use biomass, are reported in Table 1.

Table 1. List of molecules and associated companies, process and TRL

	Entity	Biomolecule	TRL	Global demand	Biomass	Production	Application
1	Michelin	Butadiene	>7	high		Catalytic chemistry	Synthetic rubber
2	ADM	Lactic acid	>5	high	X	Fermentation	Biodegradable plastics (PLA)
3	Resicare/IPPEN	HMF	>6	high	X	N/A	Precursor
4	Global Bioenergies	Isobutene	<6	high	X	Fermentation	Fuel additives
5	BASF/ OLEON	Propylene glycol		high	X	N/A	Coolants
6	Projet Incite	Monoacylglycerols	<4	NA		N/A	Food emulsifiers
7	SurfactGreen	Glycine betaine		Low			Animal feed additives
8	Naturamole	Esters					Flavors and fragrances
9	Bioinspir	Esters					Biodegradable solvents
10	STH Biotech	Canabinoid				Fermentation	Health nutraceutics
11	Orpia	Molécules issues du CNSL	3 - 6				Resins
12	Roquette	Sorbitol/Isosorbide					Bioplastics
13	Geno	Butylene glycol	>7	N/A		Fermentation	Cosmetics
14	Geno	1,4 butanediol	>7	High	X	Fermentation	Polyurethanes
15	URD ABI	p-hydroxycinnamic	<5				Food preservatives
16	UTC	Caffeoylquinic Acids	<4				Antioxidants
17	Evonik	Rhamnolipids	>6				Biosurfactants
18	Afyren	Organic acids	>6				Food preservatives
19	GF Biochemicals	Levulinic acid	>7	Medium	X		Bio-based solvents
20	Bloom Biorenewables	Lignin aromatic monomers			X		Intermediate
21	Circa	Cyrene	>6				Solvents
22	SONAE Arauco	Wood-based panels	>9	high	x		Construction, furniture

4 ID CARDS

This section provides a comprehensive "ID Card" for the bio-based molecules identified, offering detailed insights of their production pathways and technological readiness. This overview is designed to illuminate the current state and potential of these vital building blocks for a sustainable future.

4.1 Molecule Card: Bio-based Butadiene

Raw Material: Ethanol derived from biomass (plants, wood chips, rice husks, leaves, cornstalks).

Main Unit Process:

- Fermentation of non-food lignocellulosic biomass to produce ethanol.
- Conversion of fermented ethanol to butadiene.

Main Separation/Purification Processes:

- Details on specific separation and purification processes are not provided in the available resources below but could be further investigated, but typically involve a series of distillation, absorption, and extraction steps to achieve polymer-grade butadiene.

TRL:

- Pilot phase operational, indicating a TRL of 7-8 based on the demonstrator plant producing 20 to 30 metric tons per year (Axens, 2024).

Process Diagrams:

- Complete process diagrams are not detailed in public resources. However, a general flow would include biomass pretreatment, enzymatic hydrolysis, fermentation to ethanol, and catalytic conversion to butadiene (IFPEN, 2025).

4.2 Molecule Card: Lactic Acid

Raw Material: Corn-based raw materials, potentially including municipal solid waste or agricultural waste.

- Fermentation of carbohydrates such as glucose, sucrose, or lactose, derived from biomass.

Main Separation/Purification Processes:

- Fermentation broth is neutralized with calcium carbonate to produce lactate salt.
- Acidification of the lactate salt with nitric acid to recover lactic acid.
- Separation technologies involve eco-friendly approaches that produce fewer by-products and waste (Huang et al., 2023; Komesu et al., 2017) .

TRL: Joint ventures aim to make final investment decisions in 2023 (ADM, 2025). Pending these decisions and approvals, construction would begin in 2023, and production is projected for late 2025 or early 2026, indicating a TRL of approximately 5 (technology validation in a relevant environment).

Process Diagrams:

- Process diagrams for lactic acid production are presented in and consider fermentation of biomass, separation of the resulting calcium lactate and conversion to crude lactic acid, which is then purified.
- A comprehensive review of lactic acid production to purification, discussing fermentative production using renewable resources, such as lignocellulosic materials can be found in (Ojo & de Smidt, 2023).

4.3 Molecule Card: Hydroxymethylfurfural (HMF)

Raw Material: Fructose from plant-based sources.

Main Unit Process:

- Production of HMF from fructose using homogeneous catalysis.

Main Separation/Purification Processes:

- Details on specific separation and purification processes are not provided in the available resources, but generally, the production of HMF can involve dehydration of hexose sugars in an acid-catalyzed reaction with subsequent separation steps to purify the HMF.

TRL:

- The development process has been completed, including pilot-scale trials with a production of 1.2 tons of HMF. Furthermore, detailed design studies have been carried out by Technip Energies, suggesting a higher TRL indicative of readiness for industrial scaling (Speciality Chemicals Magazine, 2023).

Process Diagrams:

- The production process has been developed over ten years, from laboratory research to industrial-scale work. However, specific schematics of the process are not available in public resources. For instance, the direct synthesis of HMF from different kinds of raw biomasses has been reviewed highlighting various process advantages and considerations for commercialization (Menegazzo et al., 2018).

4.4 Molecule Card: Isobutene

Raw Material: Industrial-grade sugars, including wheat-derived glucose, sugar beet-derived sucrose, and sugars from agricultural and forestry waste.

Main Unit Process:

- The production of isobutene through a unique fermentation process that involves creating an artificial metabolic pathway in specially engineered bacteria.

Main Separation/Purification Processes:

- The process is divided into two stages. The first involves the fermentation of sugar into a precursor substance. The second stage, which must be carried out in an ATmosphere Explosible (ATEX)-rated explosion-proof reactor, involves the conversion of the precursor into isobutene (Global Bioenergies, 2023).

The production process also aligns with sustainability goals by reducing greenhouse gas emissions compared to petrochemical processes (Biofuels International, 2016). The potential to produce bio-isobutene from second generation sugars derived from agricultural residues like wheat straw, which broadens the use of non-food resources.

TRL: Global Bioenergies has successfully completed full-scale tests of their isobutene production process, indicating an advanced TRL level, but according to Table 1 it's lower than 6. They have demonstrated their process at the pilot scale and are preparing for commercial scale operations.

Process Diagrams:

- The process scheme includes fermentation followed by purification and conversion. It starts with the fermentation of sugars in a standard fermenter and finishes with a high-productivity reaction to convert

the intermediate to isobutene in an explosion-proof reactor (Global Bioenergies, 2023).

4.5 Molecule Card: Propylene Glycol (PG)

Raw Material: Glycerin derived from biodiesel production or fatty alcohols.

Main Unit Process:

- BASF and Olean have pioneered a process where glycerin is hydrogenated using a proprietary BASF copper catalyst to produce bio propylene glycol.

Main Separation / Purification Processes:

- The process involves two serial fixed bed reactors operating at temperatures between 175° to 195° Celsius and pressures of 75 or 200 bar. The crude product is further purified using a two-column distillation process to achieve a technical grade purity of over 99.5%.

TRL: The Glycerin to Propylene Glycol (G2PG) process technology is commercially proven and has been successfully operating since 2012, indicating a high TRL level (LUMITOS AG, 2012).

Process Diagrams:

- Glycerin is processed through a hydrogenolysis reaction using copper catalysts to produce bio propylene glycol, which is then purified to the desired technical or pharmaceutical grade.

4.6 Molecule Card: Monoglycerols

Annual Global Demand: The global Distilled Monoglycerides market is expected to reach a market valuation of US\$ 1,269 million by 2033 (Future Market Insights, 2025a).

Raw Material: Biobased raw materials such as vegetable oils and animal fats.

Main Unit Process:

- Monoglycerols are produced by enzymatic esterification in Olean's innovative plant, as part of the INCITE project.

Main Separation / Purification Processes:

- The process appears to be solvent-free, reducing CO₂ emissions and waste during the esterification and downstream processing, although specific purification steps are not detailed in the sources.

TRL: The project has reached a stage where enzymatic esterification has been demonstrated in real industrial settings, however it is below 4 in Table 1.

Process Diagrams:

- The enzymatic esterification process developed in the INCITE project incorporates the use of enzymes in both upstream and downstream processing to convert bio-based raw materials into esters, a key ingredient for cosmetics and food industry.

4.7 Molecule Card: Glycine Betaine

Annual Global Demand:

- The specific annual global demand figures for glycine betaine are not disclosed in the sources reviewed.

Raw Material: Beet pulp, lime, molasses, and liquid betaine obtained as by-products from sugar production.

Main Unit Process:

- Glycine betaine is produced through a fermentation process involving a bioethanol by-product called vinasses. The process developed by Danisco and Novasep represents an environmentally friendly way to produce betaine from bioethanol side-streams.
- The process and technological support details for the betaine production plant were discussed, with a focus on the environmental benefits and the ability to recycle bioethanol vinasses as crop fertilizers (« Betaine industrial production », 2011).

Main Separation / Purification Processes:

- The separation and purification processes involve proprietary chromatographic technology combined with membrane and evaporation steps (Technology Networks, 2010).

TRL:

- Given the commercial operations and industrial partnerships in place for the production of betaine, the TRL is considered high.

Process Diagrams:

- The process scheme includes using bioethanol side-streams processed through chromatography, membrane technology, and evaporation to produce betaine.

4.8 Molecule Card : Esters

Annual Global Demand: By the end of 2023, the market is likely to reach a valuation of US\$ 94.19 billion (Future Market Insights, 2025b).

Raw Material: Natural substrates, potentially including vegetable raw materials (Naturamole, 2025).

Main Unit Process:

- Naturamole utilizes biocatalytic processes, employing enzymes or microorganisms as natural micro-factories for the industrial production of molecules. This approach is part of what is known as "white biotechnology" and "green biotechnology," which are key in providing products linked to the phyto-world processed with biotech means.
- Naturamole specializes in using biocatalytic processes as an alternative to traditional chemical synthesis for making natural and sustainable molecules, serving a wide range of industrial applications
- As part of its biocatalysis technology, Naturamole develops innovative products and tailor-made bioprocesses, with a distinct approach that brings together genomics, microbiology, chemistry, and process engineering

Main Separation / Purification Processes:

- Specifics on separation and purification processes are not detailed. However, considering the use of biocatalysis and fermentation, the processes likely include filtration, centrifugation, and distillation steps tailored to the properties of the particular ester being produced.

TRL:

- Naturamole has extensive experience in various fermentation technologies and enzymatic catalysis, suggesting a 5-6 TRL for their established processes.

Process Diagrams:

- The production involves enzymatic catalysis and microbial fermentation, optimizing microorganisms and fermentation environments for high productivity. The integrative approach may include natural biodiversity screening for wild-type microorganisms and synthetic biology for recombinant microorganisms to enhance the process efficiency.

4.9 Molecule Card: Esters (Bioinspir)

Raw Material: Plant species that naturally accumulate metals in their environment.

Main Unit Process:

- Ecocatalysis®, a process combining ecology and chemistry using ecocatalysts® derived from plants. The founder is a scientist at CNRS, so it's an academic-driven startup.

Main Separation/Purification Processes:

- Not specifically mentioned, but such processes typically involve extraction, distillation, or chromatography, adapted to the properties of the produced esters.

TRL:

- The innovation and sustainable approach suggest a relevantly 4-5 TRL for the established processes.

Process Diagrams:

- Utilizes plant-based ecocatalysts® to synthesize high-value bio-sourced molecules, reducing environmental impact.

Bibliography and Key Information Sources:

- Bioinspir's approach to synthesizing molecules is geared towards sustainability, using ecocatalysts® of plant origin, which are transformed from species accumulating environmental metals (Bioinspir).

4.10 Molecule Card: Cannabinoids

Raw Material: Plant-based raw materials, specifically cannabis.

Main Unit Process:

- STH Biotech utilizes biotechnological methods (Fermentation - Plant cell culture), likely including genetically engineered microorganisms or plant tissue cultures, to enhance the production of therapeutic cannabinoid compounds (STH Biotech, 2025).
- STH Biotech has developed an innovative solution for cannabinoid production that is scalable, sustainable, cost-efficient, and consistent. They focus on the biotechnological production of cannabinoids, aiming to solve the accessibility challenges to plant-based compounds.

Main Separation/Purification Processes:

- While not explicitly detailed, processes in biotechnological cannabinoid production usually include extraction, chromatography, and crystallization.

TRL:

- STH Biotech's bioproduction platform indicates a mature technology but still low-moderate TRL (Start-up).

Process Diagrams:

- The technology amplifies plant metabolism for a significant increase in the production of target compounds, suggesting developed bioproduction techniques.

4.11 Molecule Card: CNSL-Based Products (No information from Orpia)

Raw Material: Cashew nutshell liquid (CNSL), containing anacardic acid, cardol, and cardanol.

Main Unit Process:

- Decarboxylation and distillation of CNSL to produce high-purity cardanol.

Main Separation/Purification Processes:

- The purification process includes color stabilization and separation of cardanol from other CNSL components.

TRL:

- Cardolite's technology is well-established and utilized for various commercial applications, indicating a high TRL (Cardiolite, 2025).

Process Diagrams:

- CNSL is processed to separate cardanol, which is used to manufacture epoxy curing agents, diluents, modifiers, polyols, diols, and friction particles.

4.12 Molecule Card: Isosorbide (Roquette)

Raw Material: Sorbitol, a derivative of starch.

Main Unit Process:

- Roquette produces isosorbide through the dehydration of sorbitol, employing advanced proprietary technology to ensure high purity.
- Roquette has established itself as a leader in isosorbide production for performance materials by launching the world's largest production unit, highlighting the company's commitment to innovation and sustainable practices.

Main Separation / Purification Processes:

- Isosorbide purification involves several steps to obtain grades with over 99.5% content, meeting the high-quality standards required for various applications.

TRL:

- The production of isosorbide by Roquette is at a high TRL more than 7, with a fully operational large-scale production facility.

Process Diagrams:

- The patented process developed by Roquette ensures a consistent supply of various grades of isosorbide suitable for performance plastics and other specialty chemicals.

4.13 Molecule Card: Butylene Glycol (Geno)

Raw Material: Renewable plant-based ingredients, often carbohydrates or sugars.

Main Unit Process:

- Genomatica has developed a biobased process technology, known as the GENO BG™ process, which uses fermentation to produce naturally sourced 1,3-butylene glycol.

Main Separation/Purification Processes:

- The exact details of the separation and purification process are proprietary.

TRL:

- With Genomatica having already transferred the process to large-scale fermenters, it indicates a high > TRL, showcasing the move from the developmental phase to commercial readiness.

Process Diagrams:

- The GENO BG™ process represents a sustainable alternative to conventional methods which use fossil fuel-derived acetaldehyde. It provides a purer end product, potentially suitable for various applications in personal care and other industries.

More Information:

- Genomatica's process for bio-based butylene glycol marks its entry into specialty chemicals and demonstrates a quick commercialization of bioengineering innovations that offer better performance and sustainability (Renewable Carbon News, 2017).

4.14 Molecule Card: 1,4-Butanediol (Geno)

Raw Material: Renewable plant sugars used for fermentation.

Main Unit Process:

- The GENO BDO™ process technology developed by Genomatica uses fermentation to convert plant-based sugars into 1,4-butanediol (BDO), a chemical building block for a wide range of materials.

Main Separation/Purification Processes:

- The purification of BDO typically involves several steps, although specific methods used in the GENO BDO™ process are proprietary.
- Genomatica has established itself as a leader in biobased production technologies. Their 1,4-butanediol production process is cited as a leading choice for new BDO plants due to its reliability, attractive economics, and environmental benefits. The technology is endorsed by Novamont and used by their industrial plant in Italy, meeting all performance guarantees. Genomatica has also licensed the technology to Cargill for use in the Quore venture (Renewable Carbon News, 2017).

TRL:

- The technology has proven successful at commercial scales, particularly with Novamont's confirmation of meeting all performance guarantees at its Italian industrial plant, indicating a high >7 TRL.

Process Diagrams:

- The GENO BDO™ process offers significant sustainability advantages, including an estimated 90% carbon reduction compared to traditional BDO production methods.

4.15 Molecule Card: p-Hydroxycinnamic Acid (URD ABI)

Raw Material:

- Agro-industrial byproducts, specifically compounds from mustard seed by-product and other biomass sources.

Main Unit Process:

- URD ABI focuses on the extraction of phenolic compounds like p-hydroxycinnamic acids using green chemistry principles, such as chemoenzymatic steps for functionalizing these acids.

Main Separation / Purification Processes:

- Techniques like liquid-liquid extraction assisted by a hollow fiber membrane contactor (HFMC) have been employed for the recovery of sinapic acid, a type of p-hydroxycinnamic acid, from mustard seed by-products.
- URD ABI's innovative work on valorizing by-products from the agri-food industry to extract valuable phenolic compounds is highlighted in their participation in international congresses and projects. They presented their extraction methods and participated in projects aiming to design new families of biobased UV filters starting from cellulose-derived chemical platforms.

TRL:

- The specific TRL for p-hydroxycinnamic acid production at URD ABI is not clearly stated, but the use of advanced separation technologies and engagement in international research forums suggest towards a mature level of <5 technological development.

Process Diagrams:

- URD ABI utilizes sustainable mechanosynthesis methods for creating monomers that are subsequently polymerized enzymatically, indicating advanced processing diagrams for converting biomass into high-value chemicals.

4.16 Molecule Card : Caffeoylquinic Acids (UTC)

Raw Material: Extracted from plant sources, particularly Artemisia species within the Asteraceae family, known for their rich phytochemical composition.

Main Unit Process:

- Extraction and fractionation of caffeoylquinic acids from plant materials, utilizing solvent extraction techniques.

Main Separation/Purification Processes:

- Solvent extraction followed by fractionation to isolate specific monocaffeoylquinic and dicaffeoylquinic acid compounds.

TRL:

- Established extraction and purification techniques suggest a low <4 TRL.

Process Diagrams:

- Procedures include the use of acetone extracts from wormwood species, followed by aqueous or methanolic fractionation to yield rich preparations of caffeoylquinic acids (Kamarauskaite et al., 2021).

4.17 Molecule Card: Rhamnolipids (Evonik)

Raw Material: European corn sugar, utilized as the main raw material in a fermentation process.

Main Unit Process:

- Fermentation of sugar to produce rhamnolipids, with Evonik pioneering the world's first industrial-scale production plant for bio-based and fully biodegradable rhamnolipids.

Main Separation/Purification Processes:

- While specific steps are not detailed, the manufacturing process involves fermentation followed by downstream processing to purify and isolate the rhamnolipids, ensuring high quality and sustainability.

TRL:

- The construction of the world's first industrial-scale production facility, completed ahead of schedule, signifies >6 TRL,

Process Diagrams:

- Evonik's innovation in using fermentation-based manufacturing processes for rhamnolipids supports sustainable, high-performance bio-solutions in cleaning and personal care sectors (Evonik, 2025).
- Evonik's plant is designed to meet the rapidly growing demand for environmentally friendly surfactants, utilizing bio-based raw materials and offering exceptional foam-forming properties and skin gentleness for various applications.

4.18 Molecule Card: Organic Acids (Afyren)

Raw Material: Sugar beet by-products.

Main Unit Process:

- Fermentation to produce biobased organic acids.

Main Separation/Purification Processes:

- Not specified but involves steps to ensure high purity of the acids.

TRL:

- High >6, with the first plant already operational.

Other Information:

- Afyren progress and plans for its organic acids production are outlined in their updates, highlighting their approach to industrial-scale capabilities. For detailed insights, see (AFYREN, 2023).

4.19 Molecule Card: Levulinic Acid

Annual Global Demand: The global focus on producing levulinic acid from renewable biomass as an important platform compound due to its extensive uses and high reactivity. The production from biomass, including issues with catalysis and purification, is reviewed (Signoretto et al., 2019).

Raw Material: Biomass, including agricultural residues and lignocellulosic materials.

Main Unit Process:

- The conversion of biomass to levulinic acid involves hydrolysis and subsequent dehydration of carbohydrates present in the biomass.

Main Separation/Purification Processes:

- The initial hydrolysis produces a mixture from which levulinic acid needs to be separated. This is often achieved through acid catalysis, followed by solvent extraction or distillation for purification.

TRL:

- The technology for producing levulinic acid from biomass is commercialized, with efforts focusing on optimizing yields and reducing costs. TRL Potentially around 7.

Process Diagrams:

- Process diagrams involve biomass pretreatment, hydrolysis under acidic conditions to break down carbohydrates, and dehydration to produce levulinic acid.
- Girisuta & Heeres, (2017) provide a comprehensive overview of levulinic acid synthesis from biomass, discussing the highest yields from various sources and summarizing process technology studies, including kinetic models and the status of large-scale production.

For more information:

1. Antonetti et al., (2016) discuss new frontiers in the catalytic synthesis of levulinic acid, emphasizing the transition from simple sugars to raw and waste biomasses as sustainable feedstocks for LA production .
2. Recent advances in the catalytic production of valuable levulinic acid derivatives highlight the conversion of biomass into levulinic acid as a key topic in sustainable energy supply and chemical production, suggesting future research directions and effective catalysts (Zhang et al., 2012).

4.20 Molecular Card: Lignin Aromatic Monomers

Raw Material: Lignocellulosic biomass, including hardwood, softwood, and agricultural residues.

Main Unit Process:

- Lignin depolymerization via various methods including catalytic pyrolysis, hydrothermal treatment, and oxidative breakdown, leading to the cleavage of C-O and C-C bonds in lignin to release aromatic monomers. There are many papers in this domain for the last 10 years.

Main Separation/Purification Processes:

- Following depolymerization, separation processes such as solvent extraction, distillation, and chromatography are utilized to isolate and purify aromatic monomers like vanillin, syringol, and guaiacol.

TRL:

- Lignin valorization technologies are in various stages of development, with some processes reaching pilot or demonstration scale. The overall field can be considered to have a TRL between 4 to 6, indicating ongoing validation and refinement of processes.

Process Diagrams:

- Catalytic conversion processes typically involve an initial treatment to fractionate lignin from biomass,

followed by a depolymerization step under specific catalytic and thermal conditions, and a final step of product isolation and purification.

Bibliography and Key Information Sources:

1. Catalytic scissoring of lignin into aryl monomers highlights the potential of using lignin as a sustainable source for aromatic compounds through selective conversion processes.
2. Selective production of phenolic monomers through efficient lignin depolymerization using a carbon-based nickel-iron-molybdenum carbide catalyst under mild conditions showcases the potential for high yield and selectivity in converting lignin to valuable products (Yan et al., 2021).
3. Heteroatom-participated lignin cleavage to functionalized aromatics presents an innovative approach to modify lignin-derived products, extending their application potential (Li et al., 2020).

Cyrene (dihydrolevoglucosenone) has been highlighted as a sustainable, bio-based alternative to traditional solvents like N,N-Dimethylformamide (DMF) in several studies.

4.21 Molecular Card: Cyrene

Raw Material: Cellulose-derived, through the conversion of levoglucosenone (LGO), showcasing a sustainable approach to solvent production.

Main Unit Process:

- Cyrene is synthesized in a two-step process from cellulose, emphasizing a sustainable pathway that leverages waste biomass.

Main Separation/Purification Processes:

- The production of Cyrene involves the hydrogenation of levoglucosenone, which is derived from cellulose, indicating a green chemical process that minimizes harmful by-products and relies on renewable feedstocks.

TRL: >6

Process Diagrams:

- The synthesis route for Cyrene involves environmentally benign methods that avoid the use of toxic chemicals, aligning with sustainable industrial practices.

More information:

1. **Cyrene as a Green Alternative to DMF in MOF Synthesis:** Demonstrates application in the synthesis of metal-organic frameworks (MOFs), highlighting its performance and potential as a sustainable solvent (Zhang et al., 2016).
2. **Cyrene as a Bio-Based Solvent:** Highlights Cyrene's emergence as a bio-based solvent that could replace toxic organic solvents in various organic reactions, underscoring its environmental benefits and applicability in sustainable chemical processes (Sherwood et al., 2014).

4.22 Molecular Card: Wood-based panels

Annual Global Demand: The global wood-based panel market was valued at USD 217.9 billion in 2024 and is expected to grow to USD 349 billion by 2034 (Global Market Insights, 2025).

Raw Material: Roundwood, sawdust, shavings

Main Unit Process:

- Wood raw materials are reduced to the required size and shape by chipping equipment, using one or two steps, depending on the size or shape at delivery and the desired end product quality (Raunkjær Stubdrup et al., 2016).
- Blending with diverse types of resins would provide particular properties to the particle boards.

Main Separation/Purification Processes:

- In panel manufacturing, drying the wood material—whether chips, flakes, strands, or fibers—is essential. The particles must reach the right moisture level to ensure the resin cures correctly and the panel achieves the desired quality.

TRL: This process is at commercial scale (TRL 9). SONAE Arauco, partner in the project is one of the world leaders on wood-based panels production.

Process Diagrams:

- The report of the JRC concerning wood-based panels production presents a complete process diagram of the process at high-TRL comprising chipping, drying, blending, pressing, sawing and packing (Raunkjær Stubdrup et al., 2016).

5 SELECTION OF CASE STUDIES

The selection criteria for case studies are divided into two groups: a general criteria and a process-based criteria. The first deals with: *Global demand (importance), type of biomass (feed), recyclability, data availability either from industrial partners (well-known processes) or from literature, and finally the inclusion of molecules into a lignocellulosic biorefinery.* With respect to the process-based criteria, the focus is placed on: *the use of multiple Process Operations, the knowledge about operating conditions, availability of information about energy consumption, as well as from process flow diagrams.*

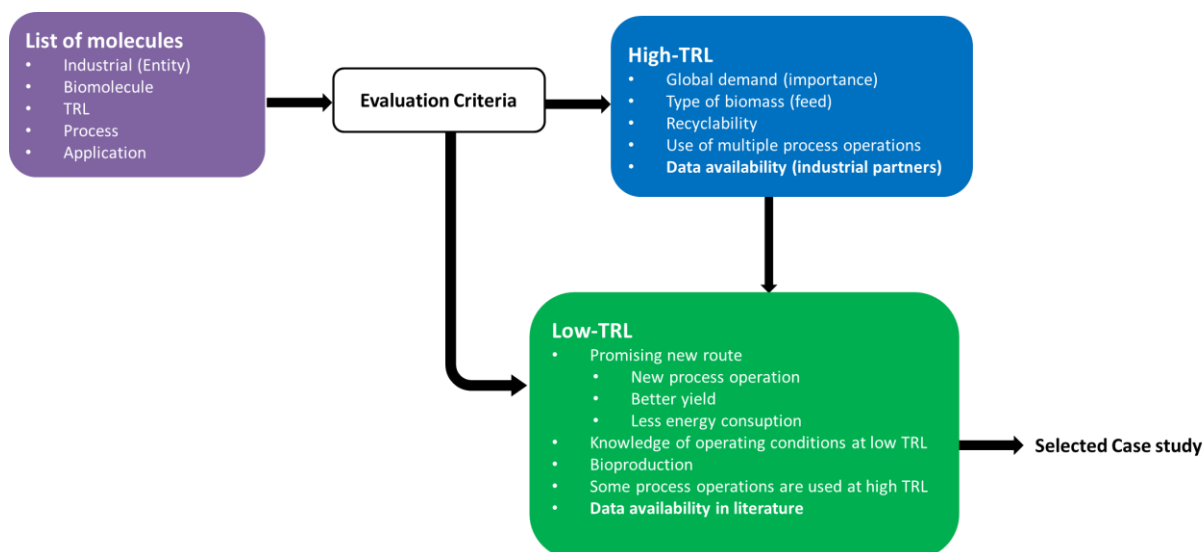


Figure 1: Methodology for the selection of the case studies

Each molecule provided in the list of Table one was assessed regarding the above-mentioned criteria. In order to choose among the different molecules, the criteria were separated regarding their TRL as displayed in Figure 1. The molecules that fulfilled most of the criteria for high and low-TRL were selected as case studies.

Preference was given to processes for which data are accessible. After contacting a large panel of stakeholders, given the data accessibility and the selection criteria, the choice was oriented towards lignin production, hydroxymethyl furfural (HMF), and wood panels (Table 2). These three products align well in a lignocellulosic biorefinery (Figure 2) that will allow to explore a wide range of processes to use and transform biomass where processes can be linked into a continuum of biomass valorization strategy.

Table 2: Case studies selected for the LCA methodology application

Product	High TRL	Low TRL
Lignin	TNO Organosolv process	AST patent Organosolv process
Wood panel	SONAE ARAUCO Particleboard	CESEFOR Particleboard
HMF	From fructose	From glucose

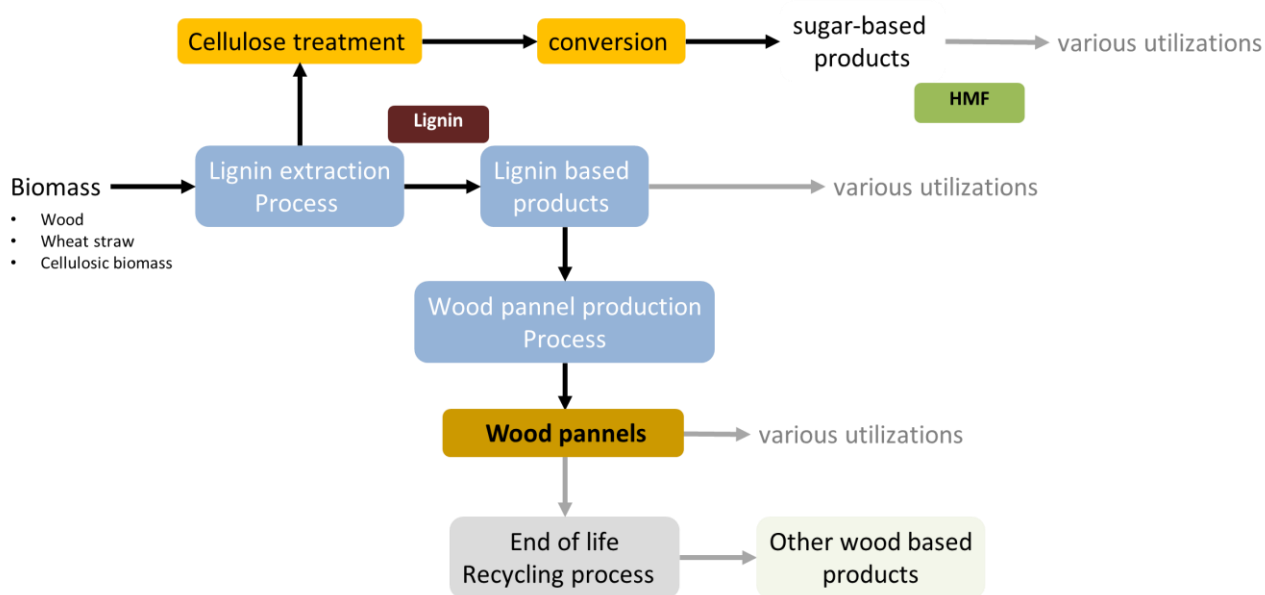


Figure 2. Lignocellulosic biorefinery scheme including the three proposed case studies.

By choosing cases where stakeholders are committed to share accurate data, the project can perform more credible tests. This approach is crucial for this type of testing, as it allows for a more realistic assessment of industrial processes, moving beyond the limitations of potentially incomplete public data.

6 CONCLUSION

This Deliverable D5.2 synthesizes the extensive research and analysis conducted to identify and evaluate the best available bio-based technologies currently available to produce molecules of interest and biomaterials. By integrating insights from comprehensive literature reviews, targeted expert interviews, and the application of rigorous selection criteria. These criteria include the data quality and availability, technological maturity of the process, and sectoral representativeness.

By systematically assessing these dimensions, the report presents a curated set of technologies that not only reflect the current state of the art in the bioeconomy landscape but also offer practical relevance for further exploration and application. The outcome serves as a basis for interactions, synergies and informed decision-making across other key work packages (WP2, WP3, and WP4), ensuring consistency and alignment in the project's broader research and innovation activities.

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